JOURNAL OF AGRICULTURAL RESEARCH

VOL. XIV WASHINGTON, D. C., JULY 22, 1918 NO. 4

A COMPARATIVE STUDY OF SALT REQUIREMENTS FOR YOUNG AND FOR MATURE BUCKWHEAT PLANTS IN SOLUTION CULTURES

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INTRODUCTION

Since the general recognition of the fact that the mineral elements essential to plant growth are derived from the soil solution and not, as suggested by Liebig, directly from the soil particles, culture solutions have assumed a very important rôle in the investigation of problems relating to plant nutrition. The first standard nutrient solution for plants was proposed by Sachs (*5*)[1] in 1860. Since then a number of formulas for the preparation of standard nutrient solutions have been suggested by different investigators. Many of the standard solutions now in common use have been recommended as producing good growth of various kinds of plants, without reference to any particular stage of development in the life cycle of the plant, for which the solutions are best adapted. It is entirely possible, however, that in a culture solution the relative proportions of the mineral constituents required to produce good growth of a given species during one physiological period might be entirely different from the proportions of the same constituents required to maintain equally good growth during another developmental period. A nutritive medium which is capable of producing good seedlings rooted in it might not be at all suitable for sustaining the development of the same plants with the approach of maturity nor for producing seed. On the other hand, a nutritive solution or other medium which is well adapted to the growth of mature plants might actually be injurious to the seedlings of the same species.

The nutrient medium recommended by Tottingham (*8*) and the 3-salt solution later proposed by Shive (*6*) are known to produce excellent growth of wheat seedlings during the first three or four weeks of development after germination. Whether these solutions are capable of sustaining the growth of wheat plants equally well throughout their entire life period, has not been determined.

[1] Reference is made by number (italic) to "Literature cited," p. 175.

Journal of Agricultural Research, Washington, D. C.

Vol. XIV, No. 4
July 22, 1918
Key No. N.J.-

As the result of extensive comparative studies with both wheat (*Triticum* spp.) (*6*) and buckwheat (*Fagopyrum esculentum*) (7), it has been found that, under certain experimental conditions and for a period of growth of about four weeks directly following germination, 3-salt solutions in suitable concentrations and with the proper proportions of the three salts, monopotassium phosphate, calcium nitrate, and magnesium sulphate (with a trace of iron added), are equal in plant-producing power to any of the more complex solutions now in common use. It seemed highly desirable to determine whether the salt proportions demanded for approximately optimum development during the later periods of growth, for the maturing of the plants, and for seed production are the same or different from those which produce the best growth during the early stages of development. An attempt has been made in this direction, and the present paper describes an experimental study of the salt requirements of buckwheat plants in water cultures, for the later periods of development from the flowering stage to the maturing of seeds. These results are compared with those of a similar study (7), previously carried out, of the development of young buckwheat plants during the growth period from germination to the flowering stage. A similar comparative study of salt requirements for buckwheat has been carried out with sand cultures. The results with water cultures will alone be presented in the following pages; those obtained with sand cultures will be reserved for later publication.

Buckwheat was chosen for these tests for the reason that in its life cycle it presents two distinct physiological growth periods which extend over nearly equal periods of time. The first of these occupies the period between the germination of the seeds and flowering, the second interval extending over the period from the flowering stage to the maturity of the seeds. It is a quick-growing plant and matures in a comparatively brief period of time, requiring, under favorable conditions, about 60 days to complete its active growing period.

EXPERIMENTAL PROCEDURE AND METHODS

The tests to be described in the following pages were carried out with the optimal series of 3-salt solutions[1] previously employed by Shive in his work with wheat and with buckwheat. This optimal series comprised 36 different solutions, all having approximately the same total osmotic concentration value of 1.75 atmospheres. The three salts were so distributed as to include all possible sets of proportions of the three salts when the partial concentrations of the three components were made to vary by equal increments of one-tenth of the total osmotic concentration. To each solution was always added the usual trace of iron, in the form of ferric phosphate.

[1]A table of these solution formulas has been given in previous publications: Shive, J. W. (*6*), and McCall, A. G. (*3*). A discussion of the methods of calculation by which the partial osmotic concentration values and also the volume-molecular partial concentrations of each salt in these solutions may be calculated, is given by Tottingham (*8, p. 177–182, 192*).

In the work previously carried out with buckwheat (7), tests of the 36 different sets of proportions of the three salts of this series showed that the best growth of tops and of roots during the early physiological growth period extending from germination to the flowering stage was produced by a solution containing the three salts in the following volume-molecular proportions: Potassium phosphate (KH_2PO_4), 0.0144 m; calcium nitrate [$Ca(NO_3)_2$], 0.0052 m; and magnesium sulphate ($MgSO_4$), 0.0200 m. This solution was further characterized by having four-tenths of its total osmotic concentration derived from potassium phosphate, four-tenths from calcium nitrate, and two-tenths from magnesium sulphate.

The methods [1] employed with the water cultures here considered were similar to those previously adopted in the work with wheat and with buckwheat. The Japanese variety of buckwheat was used. The seedlings were carefully selected for uniformity of size and vigor, and when about 5 cm in height were transferred to the culture vessels, which consisted of pint Mason jars. Each culture vessel had a capacity of 515 cc. Three buckwheat plants were included in each culture.

In order to determine the proportions of the three salts required to produce approximately optimum growth of buckwheat plants during the later period of development, from the flowering stage to the maturing of the seed, it was of course essential that the plants of all the cultures at the beginning of this later period of growth should be as nearly uniform as possible. With this in view, many more cultures than the 36 comprising the series for study were prepared at the same time with selected seedlings all nearly uniform in size and vigor. The selected seedlings were transferred to the culture vessels, each of which had previously been provided with 515 cc of the same solution. This solution, with a total osmotic concentration value of 1.75 atmospheres, had the salt proportions above given. These produced the highest dry weight yield of buckwheat tops and of roots during the early growth period, between germination and the beginning of the flowering stage. All the seedlings were grown in this solution, with renewal of solutions every four or five days during the first 24-day growth period after the seedlings had been transferred to the solutions. At the end of this time period the plants of each culture had begun to bloom and all the plants appeared healthy and vigorous, the cultures throughout showing excellent uniformity.

Thirty-six cultures were now selected from the larger number at hand; these were transferred to the 36 different solutions comprised in the optimal 3-salt series. All the solutions of the series had a total osmotic concentration value of approximately 1.75 atmospheres, but they differed from each other in the proportions of the component salts. For purposes of comparison, one culture was also transferred to Knop's

[1] For a description of the methods employed in these studies, see Shive, J. W. (6).

solution and another to Tottingham's best solution for wheat tops, each with a total concentration value equal to that of the 3-salt solutions. Thus, the actual tests of the effects of the 36 different salt combinations upon the growth of the plants in this series, were not begun until the plants had passed through the first physiological growth period extending from the germination of the seed to the flowering stage. The cultures were now continued, with renewal of solutions as before, until the seeds were mature. This required 28 days. The entire active growth period of the plants of this series extended, therefore, over an interval of 52 days after the seedlings had been transferred to the culture vessels. The series was then repeated. The second series was carried out in the same manner as the first, but under somewhat different seasonal conditions.

In order that all the plants might be exposed to somewhat similar changes of temperature, light, and moisture, the cultures were arranged in rows on a central table in the greenhouse, in such a manner as to avoid, as far as possible, unequal shading of one culture by another. Throughout the growth period the cultures were shifted in position at regular intervals, in accordance with a definite plan.

As previously stated, the culture solutions were renewed at intervals of four or five days. At the time of each renewal of solutions, the absorption (and approximately the transpirational water loss) was determined by measuring the volume of the used solution before discarding it, and subtracting this volume from the original volume (515 cc). The total transpirational water loss for each culture was obtained by summing the losses for the partial periods between each two successive changes of solution.

At the end of the growth period, after practically all the seeds were ripe, the plants were harvested. The tops were separated from the roots just above the topmost lateral root. The seeds were carefully removed from the tops, and the three portions were separately dried to constant weight at a temperature of about 103° C. The dry weights were then obtained.

Records were kept of the temperature in the greenhouse where the culture series were conducted. Daily maximum and minimum temperature readings were obtained from thermometers protected from direct sunlight. The moisture conditions of the atmosphere throughout the growth periods were indicated by means of the evaporation rates from spherical porous-cup atmometers. Several of these instruments were placed among the cultures on the greenhouse table, and daily readings were taken. These were corrected to the Livingston (*2*) standard spherical atmometer.

EXPERIMENTAL RESULTS

The first of the two culture series carried out during the later developmental growth period (between the flowering stage and the ripening of

the seeds) was conducted from October 18 to December 9, 1916. During this period the maximum temperature recorded was 30° C., on November 3, and the minimum was 11° on December 4. The rate of evaporation from the atmometer gave a daily mean of 16.8 cc, a maximum daily rate of 25.6 cc, on November 21, a minimum daily rate of 7.4 cc, on October 20, and a total water loss from the instrument of 874 cc. The second series of cultures, which was just like the first, extended over the period from December 9, 1916, to January 30, 1917. During this period a maximum temperature of 30° occurred on December 28, and a minimum of 7° on January 1. The rate of water loss from the porous-cup atmometer, indicating the evaporating power of the air gave a daily mean of 17.7 cc, a maximum daily rate of 25.2 cc, on January 13, and a minimum daily rate of 13.5 cc, on January 29. The total loss from the instrument for the entire time was 919 cc.

In the following sections, the results obtained with these buckwheat cultures grown from the flowering stage to maturity in an optimal series of 3-salt solutions with their different sets of salt proportions will be compared with those obtained from a similar study (7) previously carried out with buckwheat grown in the solution cultures of the same series, but conducted only to the flowering stage, a period of about four weeks directly after germination. The comparisons will be made with reference to the dry weights of tops and of roots and also with respect to the relative amounts of water lost by transpiration during the growth periods.

I.—DRY WEIGHTS

A.—Presentation of Data

The tops, roots, and seeds of the cultures grown to maturity were weighed separately. Three sets of dry-weight measurements are therefore available. Since the results obtained with the two corresponding series were in very close agreement, only average dry-weight yields will here be considered. These are presented in Table I. In every case these measurements represent the values obtained by averaging the corresponding data of the two series conducted during different time periods. In the first column are given the culture numbers. These refer to the positions which the cultures occupy on the triangular diagram graphically representing the variations in the salt proportions and partial osmotic concentrations of the series of solution cultures here employed. Since the scheme of diagramatic representation for this series of solution cultures has been explained in a previous publication (*6, p. 341*) and has since been employed by McCall (*3, 4*), the description of the diagram may here be omitted. Table I gives the average absolute dry weights, in grams, of tops, roots, and seeds, and also the dry-weight values in terms of the corresponding value of culture R1C1 considered as unity. These relative yields were obtained by dividing the average absolute dry-weight value of each culture by the corresponding value of culture R1C1. The maximum relative yields are here indicated by bold-face type. The

last two items in each column (numbered K and T, respectively) refer to the data obtained with the cultures grown in Knop's solution and in Tottingham's best solution for wheat tops, each with the same total concentration as the solutions of the 3-salt series. The cultures were included in each series for comparison.

TABLE I.—*Average dry weights of tops, roots, and seeds of buckwheat grown from the flowering stage to maturity in 3-salt solutions, all having a total osmotic concentration value of 1.75 atmospheres, but differing from each other in the proportions of the 3 salts; also the ratio of tops to seeds*

Culture No.	Average dry-weight yields.						Ratio of tops to seeds.
	Tops (3 plants).		Roots (3 plants).		Seeds (3 plants).		
	Absolute.	Relative to R1C1 as unity.	Absolute.	Relative to R1C1 as unity.	Absolute.	Relative to R1C1 as unity.	
	Gm.		*Gm.*		*Gm.*		
R1C1	1.808	1.00	0.132	1.00	0.789	1.00	2.30
R1C2	2.112	1.17	.176	1.33	1.128	1.37	1.65
R1C3	1.832	1.01	.164	1.24	1.203	1.52	1.52
R1C4	2.255	1.25	.228	1.73	1.838	2.35	1.21
R1C5	2.311	1.28	.251	1.90	1.687	2.14	1.36
R1C6	2.041	1.13	.187	1.24	1.229	1.56	1.66
R1C7	2.604	1.44	.270	2.05	1.551	1.97	1.68
R1C8	2.408	1.33	.269	2.04	1.493	1.89	1.62
R2C1	2.013	1.11	.184	1.39	.735	.93	2.77
R2C2	2.365	1.31	.222	1.68	1.009	1.28	2.37
R2C3	2.279	1.26	.223	1.69	1.405	1.78	1.62
R2C4	2.060	1.14	.203	1.54	1.756	2.21	1.17
R2C5	2.105	1.17	.204	1.82	1.811	2.30	1.16
R2C6	2.140	1.18	.243	1.84	1.488	1.88	1.44
R2C7	2.210	1.22	.203	1.54	1.729	2.20	1.28
R3C1	2.025	1.12	.201	1.52	1.024	1.28	1.99
R3C2	2.359	1.31	.251	1.90	1.098	1.34	2.12
R3C3	2.288	1.27	.287	2.17	2.064	2.62	1.11
R3C4	2.372	1.31	.351	2.66	1.819	2.30	1.30
R3C5	3.258	1.80	.363	2.75	1.252	1.59	2.61
R3C6	2.661	1.47	.267	2.02	1.548	1.96	1.72
R4C1	1.923	1.06	.146	1.11	.279	.35	6.89
R4C2	2.260	1.25	.232	1.76	1.428	1.81	1.58
R4C3	2.744	1.52	.280	2.12	1.035	1.31	2.64
R4C4	2.373	1.31	.247	1.87	1.709	2.26	1.39
R4C5	2.002	1.10	.232	1.76	1.623	2.06	1.24
R5C1	1.952	1.08	.187	1.42	1.133	1.44	1.47
R5C2	2.352	1.30	.212	1.61	1.582	2.01	1.49
R5C3	2.200	1.22	.241	1.83	1.265	1.72	1.73
R5C4	2.193	1.16	.207	2.05	1.711	2.18	1.23
R6C1	2.066	1.14	.177	1.34	1.494	1.90	1.39
R6C2	2.230	1.23	.255	1.93	1.443	1.83	1.55
R6C3	2.288	1.27	.260	1.97	1.542	1.96	1.49
R7C1	2.175	1.21	.191	1.45	.953	1.21	2.29
R7C2	2.304	1.27	.198	1.50	.911	1.15	2.55
R8C1	2.372	1.31	.225	1.70	.452	.57	5.24
K[a]	2.343	1.29	.262	1.99	1.334	1.78	1.76
T[a]	2.415	1.33	.369	2.80	1.402	1.70	1.73

[a] K and T represent Knop's solution and Tottingham's best solution for wheat, respectively. The data obtained from these cultures are introduced for comparison.

The relative yield of values of tops, roots, and seeds were plotted on triangular diagrams like those previously employed (7), and to which reference is made above. These diagrams represent graphically the distribution of the dry-weight yields taken directly from the proper column of averages in Table I. To facilitate the study of this distribution and to aid in making comparisons, the total range of yield values in the average series is divided into an upper one-fourth, comprising the nine cultures which produced the highest yields, a lower one-fourth, including the nine cultures giving the lowest yields, and a medium one-half, which includes the remaining cultures. These three partial ranges were outlined on the triangular diagrams to correspond to the regions of high, low, and medium yields. The areas of high yields (range of the best nine cultures) are indicated on the diagrams by small crosses, and the areas of low yields (range of the poorest nine cultures) are denoted by small circles. The position on the diagram of the culture giving the highest yield is shown by a larger cross, and that of the culture giving the lowest yield is indicated by a larger circle.

B.—Comparison of Results Obtained from Cultures Grown to Maturity With Those Obtained from Cultures Grown to the Flowering Stage

(1) DRY WEIGHTS OF TOPS

For the sake of convenience in the discussion, the culture series grown to the flowering stage (early developmental period) in the optimal series of 3-salt solutions comprising the 36 different sets of salt proportions, will be referred to as series A, while those conducted in the same series of solutions from the flowering stage to the maturity of the seed (late developmental period) will be designated as series B. The relative dry-weight data for these two average series are brought together in Table II. The second and third columns of this table present the average relative dry-weight values of tops and of roots for the various cultures of series A. In the fourth and fifth columns are given the corresponding data for series B. The actual dry weight, in grams, of culture R1C1 is given in parentheses directly below the relative value, so that the actual dry-weight value of any culture may be found by multiplying its relative value by the actual value of culture R1C1 in the same column.

TABLE II.—*Comparison of the average relative yields of tops and roots of buckwheat grown to the flowering stage with corresponding data for buckwheat grown from the flowering stage to maturity, in 3-salt solutions*

Culture No.	Series A. Average relative dry-weight yields at flowering stage.		Series B. Average relative dry-weight yields at maturity.	
	Tops.	Roots.	Tops.	Roots.
R1C1	1.00 (.528)	1.00 (.031)	1.00 (1.808)	1.00 (.132)
R1C2	.83	.98	1.17	1.33
R1C3	.79	1.07	1.01	1.24
R1C4	.60	.71	1.25	1.73
R1C5	.89	1.07	1.28	1.90
R1C6	.99	1.09	1.13	1.42
R1C7	1.00	1.18	1.44	2.05
R1C8	.84	.87	1.33	2.04
R2C1	1.03	1.15	1.11	1.39
R2C2	1.12	1.46	1.31	1.69
R2C3	.95	1.22	1.26	1.69
R2C4	1.18	1.39	1.14	1.54
R2C5	.92	1.09	1.17	1.82
R2C6	1.01	1.29	1.18	1.84
R2C7	.89	1.06	1.22	1.54
R3C1	1.07	1.07	1.12	1.52
R3C2	1.02	1.13	1.31	1.90
R3C3	.99	1.17	1.27	2.17
R3C4	.83	1.07	1.31	2.66
R3C5	1.05	1.22	1.80	2.75
R3C6	.72	.74	1.47	2.02
R4C1	1.02	1.43	1.06	1.11
R4C2	1.34	1.50	1.25	1.76
R4C3	.95	1.17	1.52	2.12
R4C4	.95	1.21	1.31	1.87
R4C5	.69	.76	1.10	1.76
R5C1	1.05	1.30	1.08	1.42
R5C2	.89	1.20	1.30	1.61
R5C3	.76	.80	1.22	1.83
R5C4	.83	.78	1.16	2.05
R6C1	.99	1.31	1.14	1.34
R6C2	.85	.92	1.23	1.93
R6C3	.66	.85	1.27	1.97
R7C1	.73	.98	1.21	1.45
R7C2	.61	.85	1.27	1.50
R8C1	.81	.91	1.31	1.70
K	.83	.95	1.29	1.99
T	1.01	1.18	1.33	2.80

The responses of the buckwheat plants to the different salt proportions of the various solutions in which they grew during the two distinct physiological growth periods here considered can best be compared by referring to the triangular diagrams of figure 1. The comparison will be made with reference to the ranges of the high and low average dry-weight values indicated by the extent of the corresponding areas of high and low yields outlined on the diagrams for the series of the two developmental periods. The average relative dry-weight data as given in Table II are here graphically represented, but the yield values are

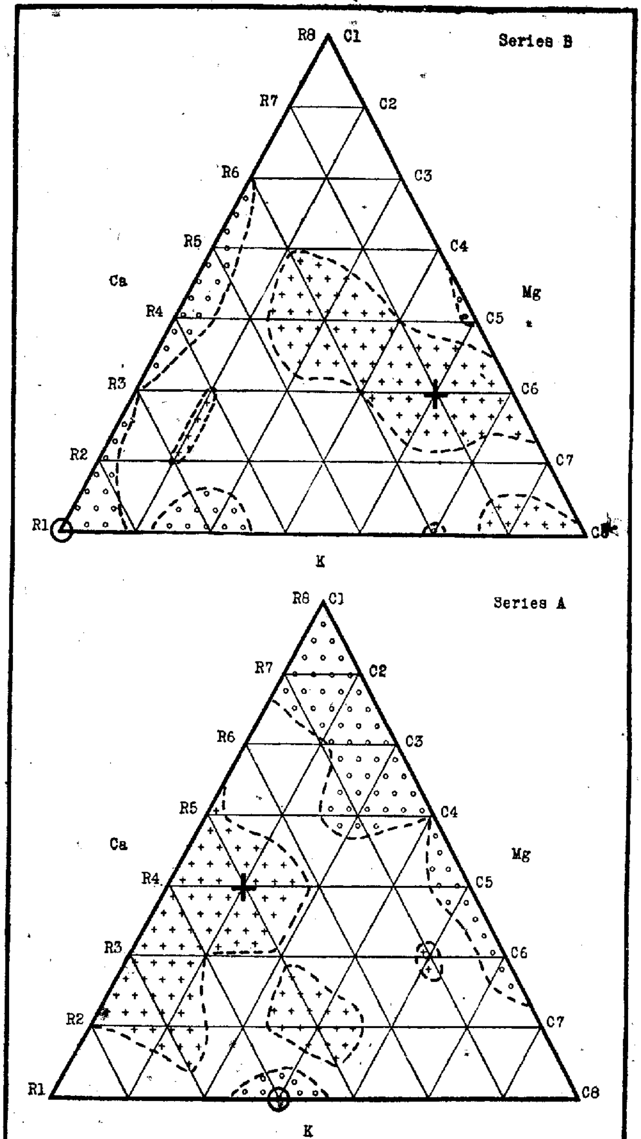

FIG. 1.—Diagrams showing relative yields of buckwheat tops. Areas of high yields are indicated by small crosses, those of low yields, by small circles. Cultures giving the highest and the lowest yields are marked by larger crosses and larger circles, respectively.

omitted to avoid confusion. The position of any culture represented on the diagrams may readily be found by means of its culture number, which always indicates the row and the number of the culture in the row. On the left margin of each diagram the rows are numbered consecutively from base to apex. The cultures of each row, represented by the points of intersection of the lines, may be considered numbered consecutively from left to right. The number of the last culture in each row is given on the right margin of the diagram. The lower triangular diagram of figure 1 represents the average yields of buckwheat tops from series A, carried out during the physiological growth period extending from germination to the flowering stage. The upper diagram represents the corresponding yields from series B, conducted from the flowering stage to the maturity of the seed.

(a) Comparison of the effects of the various osmotic salt proportions for the two different physiological growth periods. Consideration of the relative dry weights of tops.—It will be observed that in the diagram of series A (fig. 1) the main area of low yields, including eight of the nine cultures lying within the range of low dry weights of tops, extends along the right margin to the apex of the triangular diagram, while in series B the main area of low yields borders on the left margin, extending to the base of the triangle at the lower left, and includes six cultures. It is to be noted that only a single culture (R4C5) included in the low area of series A is also included in the low area of series B. There is, moreover, with the exception of this one culture, scarcely any overlapping of the areas of low yields on the diagrams of the two series. The lowest average yields of tops do not occur with corresponding cultures of the two series. The lowest average yield produced by series A and by series B occurred with cultures R1C4 and R1C1, respectively. The former is characterized by the lowest osmotic proportions of monopotassium phosphate and medium proportions of calcium nitrate and magnesium sulphate, while the latter is characterized by the lowest proportions of monopotassium phosphate and calcium nitrate, and by the highest proportion of magnesium sulphate.

The main area of high yields on the diagram of series A occupies a central region lying to the left of the vertical axis of the diagram and includes four cultures on the left margin. Two secondary high areas are also indicated for cultures R2C4 and R3C5. On the diagram of series B the main area of high dry weights occupies a central region lying mainly to the right of the vertical axis of the diagram and extends to the right margin at culture R3C6. An outlying high area is indicated at the lower right, and a smaller one about cultures R2C2 and R3C2; but these two cultures, together with culture R8C1 at the apex of the diagram, mark the lower limit of the range of high yields. The main areas of high yields of the two series are thus seen to lie on opposite sides of the diagrams, as do also the main areas of low dry weights.

A comparison of the solutions which produced the highest average yields of tops in the two series representing the two different physiological growth periods here considered, indicates the best proportions of the salts to be markedly different for the two growth periods in question. The highest yield of tops for series A occurred with culture R4C2, which is characterized, as previously stated, by having four-tenths of its osmotic value due to monopotassium phosphate, and two-tenths and four-tenths due, respectively, to calcium nitrate and to magnesium sulphate. The yield from this culture was 34 per cent higher than the corresponding yield from culture R1C1. The best physiological balance for series B is shown for culture R3C5. This culture derived three-tenths of its total osmotic value from monopotassium phosphate, five-tenths from calcium nitrate, and two-tenths from magnesium sulphate. It produced a yield of tops which was 80 per cent higher than the corresponding yield from culture R1C1. It thus appears that the greatest production of dry weight of tops in this series of 3-salt solutions, with total osmotic concentrations of 1.75 atmospheres, and for buckwheat plants during the period of growth between the flowering stage and the ripening of the seeds, may be expected with the salt proportions of solution R3C5. Thus, the maximum yield of tops was produced during the later period of growth (series B) in a medium having a lower osmotic proportion of monopotassium phosphate, a much higher proportion of calcium nitrate, and a much lower one of magnesium sulphate than the solution which produced the highest yield of tops during the early growth period (series A).

A comparative study of the diagrams of the two series thus brings out the fact that there is no similarity between the two series with respect to the distribution of the areas of high and of low dry-weight yields of tops. This is a clear indication that the response of the plants to the osmotic proportions of the salts in the solutions here employed is markedly different for the two different stages of development. Furthermore, a comparison of the total ranges of the average relative yields of the two series clearly shows that the buckwheat plants here employed respond just as readily to the variations in the proportions of the salts in the different solutions during the later period of development (series B) as they do during the early stages of growth (series A). The variation in the average relative yield values for tops in series A extends from 0.60 to 1.34, showing a total range of 0.74 from the lowest to the highest value. In series B the corresponding total range from the lowest to the highest is 0.80, extending from 1.00 to 1.80. The variations in the average yield values as given for series B must, of course, be taken as the results of the approximate differences in the growth rates of the cultures, during the time period of this series, in response to the differences in the salt proportions in the various solutions. Since, however, the cultures were carefully selected and, so far as could be judged, were

all nearly alike when the series was begun, the average yield values may be considered to approximate very closely the values which would have obtained if all the plants had been exactly alike at the beginning of the second 4-week growth period.

(*b*) COMPARISON OF THE RANGES OF THE ION RATIO VALUES FOR HIGH AND FOR LOW YIELDS OF TOPS.—The ion ratio values of the 3-salt solutions here employed have been discussed in detail in previous publications (*6, 7*) in connection with the study of the growth of young wheat and buckwheat plants in these solutions, in an endeavor to determine the relation of these ratio values to the physiological properties of the various salt combinations as they affect the growth of the plants. These ion ratio values have also been considered by McCall (*3*) in his study of young wheat plants in sand cultures.

In Table III are presented the cation ratio values of the nine cultures of each of the two series here considered, giving the highest dry weights of tops and of the nine cultures giving the lowest corresponding weights. The cultures are in every case arranged in the descending order of the values of the magnesium to calcium ratio. These cultures are the ones included in the areas of high and of low yields outlined on the triangular diagrams of figure 1. The table is divided into two vertical sections; the first section gives the culture numbers and the three cation ratio values of each of the nine cultures which produced high yields and the nine which gave low yields of tops in series A and also the total range in the magnitude of these ratio values. The second section presents the corresponding data for series B. At the bottom of the table are given the maximum and minimum ratio values and the total ranges of these for the entire series. The ratio values of the culture giving the highest yield in each series are indicated in bold-face type, while those of the culture giving the lowest dry weight appear in italics.

It will be observed that the ion-ratio values characterizing the cultures in each of the two series giving high and low yields of tops are limited to certain ranges of these ratio values, which are less extensive than the total ranges for the entire series.

From a comparison of the ratio values for the group of cultures producing high yields in series A with those of the corresponding group in series B, it may be seen that there is substantial agreement between the two series with respect to the ranges of the magnesium to potassium ratio values. This group of cultures in each of the two series is characterized by a relatively low range of values for this ratio, the range being 3.93 for series A and 3.71 for series B. There is, however, no such agreement between the two series with respect to the range of the values for the magnesium to calcium and calcium to potassium ratios. The range of the former is high (12.69) in series A and relatively low (5.53) in series B, while the range of the latter is relatively low (1.30) in series A and high (5.22) in series B.

TABLE III.—*Comparison of ion ratio values of cultures producing high and low yields (best nine and poorest nine cultures) of buckwheat tops during the early period of growth (series A) with corresponding data for cultures grown during the late period of growth (series B)*

Series A (early growth period.)				Series B (late growth period).			
Culture No.	Magnesium : calcium.	Magnesium : potassium.	Calcium : potassium.	Culture No.	Magnesium : Calcium.	Magnesium : potassium.	Calcium : potassium.
High yields:				High yields:			
R2C1	13.46	4.86	0.36	R2C2	5.77	4.17	0.72
R3C1	11.55	2.87	.24	R3C2	4.81	2.32	.84
R4C1	9.61	1.74	.18	R4C3	1.92	1.04	.54
R5C1	7.70	1.11	.14	R3C4	1.44	1.39	.96
R2C2	5.77	4.17	.72	R4C4	.96	.69	.72
R3C2	4.81	2.32	.84	R3C5	.77	.93	1.20
R4C2	3.85	1.39	.36	R1C7	.55	2.78	5.04
R2C4	1.92	2.77	1.44	R3C6	.32	.46	1.44
R3C5	.77	.93	1.20	R1C8	.24	1.39	5.76
Range	12.69	3.93	1.30	Range	5.53	3.71	5.22
Low yields:				Low yields:			
R7C1	3.85	.40	.10	R1C1	*15.40*	*11.10*	*.76*
R1C4	*2.40*	*6.95*	*2.88*	R2C1	13.46	4.86	.36
R8C1	1.92	.18	.09	R3C1	11.55	2.76	.24
R3C4	1.44	1.39	.96	R4C1	9.61	1.74	.18
R5C3	1.28	.56	.43	R5C1	7.70	1.11	.14
R7C2	.96	.20	.20	R6C1	5.77	.69	.12
R6C3	.64	.23	.36	R1C3	3.85	8.34	2.16
R4C5	.38	.35	.90	R1C6	.96	4.17	4.32
R3C6	.32	.46	1.44	R4C5	.38	.35	.90
Range	3.53	6.77	2.79	Range	15.02	10.75	4.20
Entire series:							
Maximum	15.40	11.10	5.76				
Minimum	.24	.18	.09				
Range	15.16	10.92	5.67				

The cultures R4C2 and R3C5, which produced the highest yields of tops in series A and series B, respectively, agree in showing relatively low values for all three cation ratios, although there is considerable difference between the corresponding ratio values for the two cultures. The values of the three ratios magnesium to calcium, magnesium to potassium, and calcium to potassium for the culture (R4C2) producing the maximum yield of tops in series A are 3.85, 1.39, and 0.36, respectively, while the corresponding ratio values for the culture (R3C5) which produced the highest yield in series B are 0.77, 0.93, and 1.20, respectively.

On comparing now the ranges in the ratio values as given in Table III for low yields it will be observed that there is no agreement between the groups of cultures producing low dry weights in the two different series, with respect to the ranges in the magnitudes of any two corresponding ratios. Thus, the group of cultures of series A giving low yields of tops is characterized by a relatively low range of values for the ratio mag-

nesium to calcium, and an intermediate range for the ratios magnesium to potassium and calcium to potassium, while the group of cultures which produced low yields in series B shows a wide range in the values for each of the three ratios.

The individual culture R1C4 giving the lowest dry weight of tops in series A shows a low magnesium to calcium ratio value of 2.40 and intermediate values of 6.95 and 2.88 for the ratios magnesium to potassium and calcium to potassium, respectively. Culture R1C1, which gave the lowest yield of tops in series B, is characterized by the maximum values of the ratios magnesium to calcium and magnesium to potassium, and by a low value of the ratio calcium to potassium. The values of these three ratios are 15.40, 11.10, and 0.76, respectively. Thus, there is no agreement between any two corresponding ratio values characterizing the individual cultures which produced the minimum yields in their respective series.

From the above considerations it is at once clear that these ion ratio values and the dry-weight yields of tops are not at all related in the same way in the two series representing the two physiological stages of development in the active growth period of the plants. This is still further emphasized by the marked differences in the atomic proportions characterizing the solutions producing the highest and lowest yields in the two series. Thus, for example, the highest yield in series A occurred with the solution R4C2, having the ratio values as follows: magnesium to calcium, 3.85; magnesium to potassium, 1.39; and calcium to potassium, 0.36. This indicates that the best solution for tops in this series contains 1.39 atoms of magnesium and 0.36 atoms of calcium for each single atom of potassium (by assuming, of course, that the number of atoms of an element present in a given mass of it is proportional to the number of gram-atoms contained in the mass). The solution (R3C5) which produced the highest yield in series B possessed 0.93 atoms of magnesium and 1.20 atoms of calcium for each atom of potassium. The difference between the atomic proportions characterizing the solutions in the two series which produced the poorest growth of tops is even more pronounced than is that between the atomic proportions characterizing the solutions which produced the highest yields. The solution (R1C4) giving the lowest yield of tops in series A had the atomic proportions magnesium, 6.95; calcium, 2.88; and potassium, 1.00, while the solution (R1C1) giving the lowest yield of tops in series B, possessed the proportions magnesium, 11.10; calcium, 0.76; and potassium, 1.00. It is thus obvious that the atomic proportions characterizing the solutions producing the best and also the poorest yields of tops vary markedly with the different growth periods here considered.

(2) DRY WEIGHTS OF ROOTS

The average relative dry weights of roots are given in Table II in connection with the corresponding data for tops. These relative root yields

have been plotted on triangular diagrams like those of figure 1, which graphically represent the relative yields of tops. The effect of the differences in the developmental stages of the plants upon the positions and ranges of the areas of high and low yields of roots will be compared by referring to the triangular diagrams of figure 2, in which the lower diagram represents the average yields of roots from series A, and the upper one represents the yields from series B.

(a) Comparison of the effects of the various osmotic salt proportions for the two physiological growth periods—Consideration of the relative dry weights of roots.—A comparison of the diagram of series A with that of series B shows the main areas of low yields to lie on opposite margins of the diagram. There is no overlapping of the areas of low yields. The cultures (R1C4 and R1C1) producing lowest yields of roots in series A and B, respectively, are the same ones which produced also the minimum yields of tops in the corresponding series. The osmotic proportions of the three salts characterizing these two solutions are therefore the same for both tops and roots.

The main areas of high yields on the two diagrams occupy central regions lying chiefly on opposite sides of the vertical axes of the diagrams. The main high area of series A extends to the left and includes the three marginal cultures R4C1, R5C1, and R6C1, while the main area of high yields on the diagram for series B extends to the right margin at culture R3C6. There is a certain amount of overlapping of the areas of high yields, but only a single culture is shown which is common to areas of high yields on the two diagrams. This culture (R3C5), which marks the lower limit of the range of high yields in series A, produced the maximum yield in series B. The maximum yield of roots in series A and that in series B occurred with the cultures R4C2 and R3C5, respectively. These two cultures have already been shown on the diagrams of figure 1 as producing the highest dry weights of tops in their respective series. Thus the osmotic proportions characterizing these two solutions, like those characterizing the solutions producing the lowest yields in the two series are the same for both tops and roots.

It is obvious that there is as little similarity, with respect to the distribution of the areas of high and low yields, between the two diagrams representing the yields of roots (fig. 2) as there is between those representing the yields of tops (fig. 1). From these considerations it is clear that the various osmotic proportions of the three salts in the solutions here employed affect the growth of roots as differently during the two developmental periods as they do the growth of tops.

A comparison of the two diagrams of figure 2 with the corresponding ones of figure 1, representing the relative yields of tops, brings out some very striking correlations between the growth of tops and that of roots. As has already been pointed out, the cultures in each of the two series which produced the highest yields of tops, gave also the maximum root

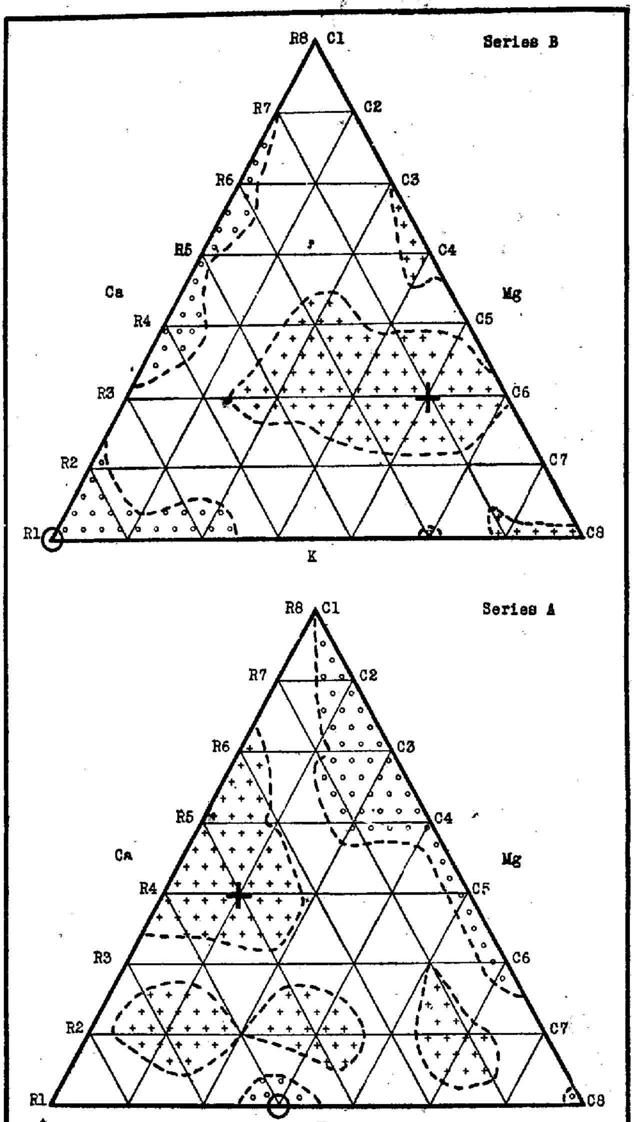

FIG. 2.—Diagrams showing relative yields of buckwheat roots. Areas of high yields are indicated by small crosses, those of low yields by small circles. Cultures giving the highest and lowest yields are marked by larger crosses and larger circles, respectively.

yields, while the cultures which yielded the lowest dry weights of tops gave also minimum root yields. It will further be observed that the diagrams graphically representing the dry weights of tops (fig. 1) and the corresponding ones representing the relative yields of roots, show a very pronounced similarity with respect to the positions and ranges which the areas of high and low yields occupy on the diagrams.

(b) COMPARISON OF THE RANGES OF THE ION RATIO VALUES FOR HIGH AND FOR LOW YIELDS OF ROOTS.—The cation ratio values of the nine cultures producing the best yields of roots, and also the group of nine cultures giving the poorest yields, and the ranges of these values for each of the two series here considered, are presented in Table IV, which conforms in every respect to Table III. As in the case of top yields, the ion ratio values for the best nine and the poorest nine cultures in each of the two series are limited to certain ranges of these ratio values, which are always less extensive than the corresponding total ranges for the entire series.

TABLE IV.—*Comparison of ion ratio values of cultures producing high and low yields (best nine and poorest nine cultures) of buckwheat roots during the early period of growth (series A) with corresponding data for cultures grown during the late growth period (series B)*

Series A (early growth period).				Series B (late growth period).			
Culture No.	Magnesium: calcium.	Magnesium: potassium.	Calcium: potassium.	Culture No.	Magnesium: calcium.	Magnesium: potassium.	Calcium: potassium.
High yields:				High yields:			
R4C1	9.61	1.74	0.18	R3C3	2.56	1.85	0.72
R5C1	7.70	1.11	.14	R4C3	1.92	1.04	.54
R2C2	5.77	4.17	.72	R3C4	1.44	1.39	.96
R6C1	5.77	.69	.12	R3C5	.77	.93	1.20
R4C2	3.85	1.39	.36	R6C3	.64	.23	.36
R2C3	3.21	3.47	1.08	R1C7	.55	2.78	5.04
R2C4	1.92	2.77	1.44	R5C4	.48	.28	.58
R3C5	.77	.93	1.20	R3C6	.32	.46	1.44
R2C6	.64	1.39	2.16	R1C8	.24	1.39	5.76
Range	8.97	3.48	1.32	Range	2.32	2.55	5.40
Low yields:				Low yields:			
R1C4	*2.40*	*6.95*	*2.88*	R1C1	*15.40*	*11.10*	.72
R8C1	1.92	.18	.09	R2C1	13.46	4.86	.36
R5C3	1.28	.56	.43	R4C1	9.61	1.74	.18
R7C2	.96	.20	.20	R5C1	7.70	1.11	.14
R6C3	.64	.23	.36	R1C2	6.74	9.72	1.44
R5C4	.48	.28	.58	R6C1	5.77	.69	.12
R4C5	.38	.35	.90	R1C3	3.85	8.34	2.16
R1C8	.24	1.39	5.76	R7C1	3.85	.40	.10
R3C6	.32	.46	1.44	R1C6	.96	4.17	4.32
Range	2.16	6.77	5.67	Range	14.44	10.70	4.22
Entire series:							
Maximum	15.40	11.10	5.76				
Minimum	.24	.18	.09				
Range	15.16	10.92	5.67				

From Table IV it will be observed that the iron-ratio ranges for the cultures giving high or low yields of roots vary as markedly and in the same manner with the two different developmental growth periods (series A and B) as they do for the corresponding yields of tops. Thus, the cultures giving high root yields in series A show a wide range (8.97) in the magnesium to calcium ratio values and low ranges (3.48 and 1.32, respectively) in the values of the magnesium to potassium and calcium to potassium ratios, while the cultures of series B giving corresponding yields possess low ranges (2.32 and 2.55, respectively) for the magnesium to calcium and the magnesium to potassium ratio values, and a wide range (5.40) in the values of the calcium to potassium ratio. The group of cultures which produced low root yields in series A shows a low range (2.16) of values for the magnesium to calcium ratio, an intermediate range (6.77) for the magnesium to potassium ratio, and a wide range (5.67) for the calcium to potassium ratio. In series B the group of cultures giving low yields of roots is characterized by wide ranges in the values of all three ratios. These values are 14.44, 10.70, and 4.22, for the ratios magnesium to calcium, magnesium to potassium, and calcium to potassium, respectively.

A comparison of the data in Table III with those in Table IV brings out the fact that nearly all the ratio ranges for the cultures producing either high or low yields of tops show substantial agreements with the corresponding ranges for the cultures in the same series giving high or low root yields. It thus appears that the relation of high or low root yields to the proportions of the chemical ions is, in a general way, similar to the relation of the high and low yields of tops to these ion-ratio values. This follows, of course, from the general similarity of the positions and ranges of the areas of high and low yields on the corresponding triangular diagrams of figures 1 and 2. Since in the same series the maximum yields of tops and of roots occurred with the same culture, as did also the minimum yield of tops and of roots, there is but one set of ratio values for the two kinds of maximum yields and one set for the two kinds of minimum yields for each of the two series.

(3) DRY WEIGHTS OF SEEDS

The absolute and relative dry weights of seeds obtained from the cultures of series B are presented in Table I, in connection with the corresponding data for tops and for roots. The absolute dry weight values represent, in each case, the averages from two series. The relative values were obtained, as were also the relative yields of tops and of roots, by dividing the average absolute dry weight value for each culture by the corresponding value for culture R1C1. The ratios of top yields to the yields of seeds are given in the last column of Table I. These ratio values represent the yields of tops expressed in terms of the corresponding yields of seeds considered as unity.

The average relative yields of seeds are represented graphically on the triangular diagram of figure 3, in the same manner as are the yields of tops and of roots on the diagrams of figures 1 and 2, respectively. The range of the average relative yields of seeds extends from 0.35 to 2.62. On the diagram representing these yields the main area of high dry weights (2.14–2.62) occupies a central region at the base of the triangle, extending upward to the right margin at culture R5C4. A small outlying high area is also indicated about culture R2C7. The highest yield of seeds occurred

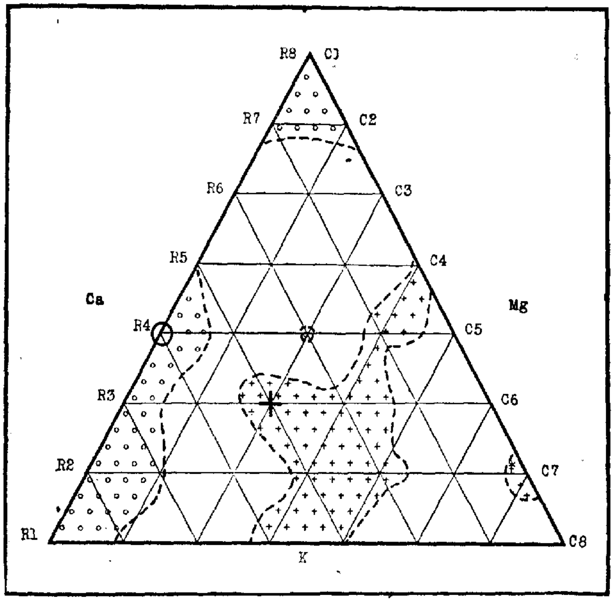

FIG. 3.—Diagram showing relative yields of buckwheat seeds. Areas of high yields are indicated by small crosses, those of low yields by small circles. The culture giving the highest yield is marked by a larger cross, that giving the lowest yield by a larger circle.

with culture R3C3, which produced a medium yield of tops. The main area of low yields (0.35–1.31) extends along the left margin to the base of the triangle, and a smaller low area is shown at the apex and another at culture R4C3 at the center of the diagram. The lowest yield of seeds was produced by the plants of culture R4C1. A comparison of the diagram of figure 3 with the upper diagram of figure 1, representing the yields of tops, shows that there is little correlation between high top yields and the production of large yields of seeds. Only two cultures, R3C4 and R4C4, which produced high top yields are included in the areas of high yields of seeds, and these two cultures mark the lower limit in the range of high yields of tops. On the other hand, the main area of

low yields of seeds, extending along the left margin of the diagram, has a corresponding area of low top yields. It is to be noted, however, that two cultures, R_2C_2 and R_4C_3, which produced high dry weights of tops, lie within the areas of low yields of seeds.

It thus appears that the yields of tops and of seeds do not vary in the same way with reference to the variations in the proportions of the three salts in the solutions. It is entirely possible, of course, that this lack of correlation between the growth of tops and the production of seed is related to other factors than the physiological properties of the media in which the plants were grown. Several of the more important of these factors may here be mentioned. The plants of a series of cultures like those here employed must vary greatly in the degree of productiveness, which is certainly much higher in some plants than in others, even when grown under exactly similar conditions with respect to the medium and the aerial surroundings. This is apparently an hereditary quality and one certainly not easily to be controlled in experiments of this character. Furthermore, these series of cultures were conducted during a season of the year when insect pollination was not possible, and pollination by artificial means was perhaps imperfectly accomplished, or it may have been less perfectly accomplished with some of the cultures than with others. Either one or both of these factors may have exerted an influence upon the manner in which the yields of seeds varied throughout the series. Whatever influence these factors may have had upon seed production, it is certain that an abundance of seed was produced by nearly all the cultures, as will be seen from an inspection of the last three columns of Table I, giving the numerical data of seed yields. From the last column of this table showing the ratios of the yields of tops to the yields of seeds, it will be observed that the ratio values for eight cultures lie between 2.0 and 3.0, while the ratios for 26 cultures have values between 1.0 and 2.0. The average of these ratio values for the entire series is 1.94. This indicates that the average yield of tops for the entire series is less than double the corresponding yield of seeds. Nearly all the seeds obtained from these cultures were large, fairly uniform in size, and well filled. Very few small or imperfectly formed seeds were present.

II.—TRANSPIRATION AND WATER REQUIREMENTS

As previously stated, the total amount of water lost by transpiration during the growth period was determined for each culture by summing the losses recorded for the partial periods between each two successive changes of solutions. From the total water loss for each culture considered in connection with the dry weights of tops, of roots, and of seeds, have been derived the ratios representing the amount of water lost by transpiration for each single gram of dry plant substance produced. These ratios of transpiration to yields represent the water requirements of the plants. Table V presents the data of transpiration for the series

(A and B) of the two developmental periods here considered, and also the data of water requirements for the cultures of the two series. The various measurements for each culture are expressed in terms of the corresponding measurement for culture R1C1 in the respective columns. The actual value for this culture is given in each case in parentheses just below the relative value, 1.00. In columns 2 and 3 are given the relative amounts of water loss for the cultures of series A and B, respectively. Then follow two columns presenting the relative water requirements of tops and roots for series A. The last three columns give the relative water requirements for tops, roots, and seeds, for series B.

TABLE V.—*Data of transpiration and water requirement: series A, grown to the flowering stage; series B, grown from the flowering stage to maturity in 3-salt solutions*

Culture No.	Transpiration.		Water requirements.				
			Series A.		Series B.		
	Series A.	Series B.	Tops.	Roots.	Tops.	Roots.	Seeds.
R1C1	1.00 (205)	1.00 (763)	1.00 (389)	1.00 (6710)	1.00 (478)	1.00 (5999)	1.00 (1282)
R1C2	.84	1.12	1.01	1.08	.91	.87	.75
R1C3	.97	1.10	.99	.90	1.05	.97	.66
R1C4	.67	1.12	1.17	.95	.86	.71	.73
R1C5	.95	1.19	1.06	.88	.88	.78	.65
R1C6	1.06	1.10	1.06	.89	.96	.77	.62
R1C7	1.08	1.40	1.08	.92	1.00	.78	.88
R1C8	.96	1.29	1.13	1.10	.96	.85	.67
R2C1	1.03	1.03	1.00	.90	.99	.93	1.12
R2C2	1.18	1.17	1.05	.81	.83	.66	.81
R2C3	.96	1.43	1.01	.79	1.19	.98	.99
R2C4	1.12	1.33	.95	.81	1.10	.99	.52
R2C5	.91	1.34	.98	.84	1.13	.86	.60
R2C6	1.06	1.29	1.05	.82	1.14	.84	.71
R2C7	1.06	1.26	1.15	.93	.95	.82	.50
R3C1	.99	1.15	.92	.92	.83	.69	.71
R3C2	.98	1.23	.95	.86	.92	.80	.95
R3C3	1.01	1.36	.84	.73	1.08	.65	.58
R3C4	.91	1.37	1.11	.85	.99	.68	.89
R3C5	1.26	1.46	1.20	1.03	.67	.44	.61
R3C6	.81	1.36	1.13	1.10	.85	.67	.64
R4C1	1.05	.76	1.03	.73	.66	.70	1.63
R4C2	1.07	1.36	.99	.84	1.09	.90	.72
R4C3	.98	1.25	1.03	.83	.76	.73	1.23
R4C4	1.03	1.31	1.08	.85	.98	.75	.84
R4C5	.87	1.17	1.27	1.15	1.04	.93	.75
R5C1	1.07	.83	1.02	.82	.69	.61	2.30
R5C2	1.04	1.34	1.17	.87	1.06	.85	.67
R5C3	.91	1.18	1.19	1.13	1.07	.74	.73
R5C4	.95	1.34	1.15	1.23	1.12	.82	.79
R6C1	1.00	1.13	1.00	.75	.97	.83	.72
R6C2	.96	1.22	1.13	.99	.96	.70	.74
R6C3	.84	1.36	1.24	.97	1.11	.87	.86
R7C1	.88	1.16	1.19	.89	.90	.85	1.26
R7C2	.75	1.17	1.21	.87	.92	.90	2.34
R8C1	1.03	1.08	1.29	1.13	.75	.67	.70
K	.93	1.36	1.11	.98	1.01	.58	1.71
T	1.15	1.25	1.14	.97	1.03	.66	1.25

In order to facilitate comparisons, the average data of Table V were plotted on triangular diagrams in the same manner as were the dry-weight yields. The corresponding diagrams of the two series thus obtained were then compared and a comparison was also made with the corresponding yield diagrams (fig. 1, 2). These diagrams graphically representing the average data of Table V are not here given, but the chief points brought out by these comparisons are presented below:

A.—Relation of Transpiration to Yields

A comparison of the transpiration diagrams of series A with the corresponding yield diagrams shows the main areas indicating high transpiration rates, and also those denoting low rates, to occupy positions corresponding fairly well, though not absolutely, with the areas of high and of low yields, respectively, both of tops and of roots. In series B there is equally good agreement between transpiration and yields of tops and of roots, both for the areas of high yields and for those of low yields. It is thus clear that, in general, high transpiration corresponds to high yields of tops and of roots for each of the two developmental periods represented by series A and series B. It is to be emphasized, however, that there is no agreement between the areas of high and low values on the corresponding transpiration diagrams of the two series. This is a clear indication that the relation between the various salt proportions and transpiration is as widely different with respect to the two periods of development here considered as is the relation between these salt proportions and the yields, either of tops or of roots.

B.—Relation of Water Requirements to Yields

A study of the five triangular diagrams representing the water requirement data in Table V brings out several interesting relations. Thus, in series A, a definite relation is shown between the water requirements of tops and top yields and also between the water requirements of roots and root yields. On the diagram representing water requirements of tops, in this series, the areas of high values correspond to the areas of low values on the diagram of top yields, while the regions of low water requirement values correspond to the areas of high top yields. These relations are shown to hold equally well between the water requirements of roots and root yields. In series B the diagrams representing the water requirements of tops and of roots, when compared with the corresponding yield diagrams, show a marked tendency toward the same relations. This is particularly true with respect to the relations between low water requirements and high yields, both for tops and for roots, although the agreements are not so exact as they are in series A. There is, however, no detailed agreement between the areas of low yields and those of high water requirements.

A comparison of the water requirement diagram for seeds with the corresponding yield diagram indicates a very close agreement between the areas representing high water requirement and those of low yields. The areas of low water requirement values correspond also, in a general way, with the areas of high yields.

From the above observations it is clear that a fairly definite relation exists between the dry-weight yields and water requirements for each of the two series of buckwheat plants here considered. This relation may briefly be stated as follows: In general, high yields of tops, roots, and seeds correspond to low water requirements, and low yields correspond to high water requirements. It is thus to be expected that favorable conditions for the growth of these plants are associated with relatively low water requirements, while unfavorable conditions for growth will demand a relatively larger amount of water to produce 1 gm. of dry plant substance.

A comparison of the water-requirement diagrams of series A with the corresponding diagrams of series B brings out the fact that there is no similarity between the diagrams of the two series representing the two developmental growth periods with respect to the positions and distribution of the areas of high and low water requirement values. Thus there is a marked difference in the manner in which the water-requirement values of the two series vary with respect to the variations in the salt proportions of the solutions employed.

From the preceding considerations of the various plant measurements it is at once clear that the relation of the growth rate of the buckwheat plants to the proportions of the three salts in the solutions here employed is markedly different for the early and late developmental periods represented by series A and series B, whether this relation is judged by the criterion of dry weights of tops or of roots, by that of transpiration, or by that of water requirements of tops or of roots.

It is to be emphasized, of course, that the changes in the physiological requirements of these plants, with respect to the salt proportions, may be a gradual process extending over a comparatively long time period. Such a change might even begin soon after germination of the seed and continue during the entire active growth period of the plants. If, therefore, the entire growth period should be divided into a larger number of partial periods than the two which have here been considered, and the best physiological balance of salt proportions determined for each, these partial periods might possibly call for other salt proportions for the production of maximum yields than the ones which gave the highest yields during the first or during the last 4-week period of these tests. On the other hand, the change in the salt requirements of the plants may take place comparatively rapidly with the marked changes which occur within the plants during the period of blossoming, when the vegetative processes become less active and the reproductive and seed-forming processes begin.

SUMMARY

The preceding pages present a comparative study of the salt requirements for young and for mature buckwheat plants grown in nutrient solutions having the same initial total concentration value of 1.75 atmospheres, but differing in the proportions of the component salts. This series of solutions comprised 36 different sets of salt proportions of the three salts, potassium phosphate (KH_2PO_4), calcium nitrate[$Ca(NO_3)_2$], and magnesium sulphate ($MgSO_4$).

The results obtained from a series of cultures grown in these solutions, from the flowering stage to the maturity of the plants, were compared with those obtained from a similar series previously carried out with the same solutions but conducted only to the flowering stage. The main results of this comparative study may be summarized briefly as follows:

(1) The highest yield of buckwheat tops and of roots obtained in a period of four weeks directly following germination was produced by a solution characterized by the following salt proportions: Potassium phosphate, 0.0144 m; calcium nitrate, 0.0052 m; magnesium sulphate, 0.0200 m. The buckwheat plants grown during the second four-week period (including the period of seed production and ripening) in the same series of 3-salt solutions as were the plants harvested at the end of the first four-week period produced their highest yield of tops and of roots in a solution having the salt proportions of potassium phosphate, 0.0108 m; calcium nitrate, 0.0130 m; magnesium sulphate, 0.0100 m. Thus, the maximum yield was produced during the later stage of development (series B) in a medium having a lower osmotic proportion of potassium phosphate, a much higher proportion of calcium nitrate, and a much lower one of magnesium sulphate than had the medium which produced the highest yield during the early growth period (series A).

(2) The buckwheat plants respond just as readily to the variations in the osmotic proportions of the salts in the different solutions during the later period of development as they do during the early stage of growth, but this response is markedly different for the two different stages of development.

(3) The values of the cation atomic ratios magnesium to calcium, magnesium to potassium, and calcium to potassium, characterizing the solutions which produced the highest yields, and also those which gave the lowest yields, differ markedly with the two different developmental stages of the plants.

(4) The amounts of transpirational water loss during each of the two different periods of development, indicate, in a general way, the yields. High transpiration corresponds to high yields of tops, and low transpiration to low yields.

(5) For each of the two developmental periods of growth considered, low water requirement is, in general, associated with high yields of tops and of roots, and high water requirement with low yields.

(6) There is no definite correlation between the yields of tops and of seeds, such as there is between the yields of tops and of roots.

LITERATURE CITED

(1) KNOP, W.

1862. QUANTITATIV-ANALYTISCHE ARBEITEN ÜBER ERNÄHRUNGSPROCESS DER PFLANZEN. II. *In* Landw. Vers. Stat., Bd. 4, p. 173–187.

(2) LIVINGSTON, B. E.

1915. ATMOMETRY AND THE POROUS CUP ATMOMETER. *In* Plant World, v. 18, no. 2, p. 21–30; no. 3, p. 51–74, 8 fig.; no. 4, p. 95–111; no. 5, p. 143–149.

(3) McCALL, A. G.

1916. PHYSIOLOGICAL BALANCE OF NUTRIENT SOLUTIONS FOR PLANTS IN SAND CULTURES. *In* Soil Science, v. 2, no. 3, p. 207–253, 8 fig., 1 pl. Literature cited, p. 251–253.

(4) ——— ———

1917. THE PHYSIOLOGICAL REQUIREMENTS OF WHEAT AND SOYBEANS GROWING IN SAND MEDIA. *In* Proc. 27th Ann. Meeting Soc. Prom. Agr. Sci., 1916, p. 46–59, 2 fig.

(5) SACHS, JULIUS.

1860. VEGETATIONSVERSUCHE MIT AUSSCHLUSS DES BODENS ÜBER DIE NÄHRSTOFFE UND SONSTIGEN ERNÄHRUNGSBEDINGUNGEN VON MAIS, BOHNEN UND ANDEREN PFLANZEN. *In* Landw. Vers. Stat., Bd. 2, p. 219–268.

(6) SHIVE, J. W.

1915. A STUDY OF PHYSIOLOGICAL BALANCE IN NUTRIENT MEDIA. *In* Physiol. Researches, v. 1, no. 7, p. 327–397, 15 fig.

(7) ——— ———

1918. A STUDY OF PHYSIOLOGICAL BALANCE FOR BUCKWHEAT IN THREE-SALT SOLUTIONS. N. J. Agr. Exp. Sta. Bul. 319.

(8) TOTTINGHAM, W. E.

1914. A QUANTITATIVE CHEMICAL AND PHYSIOLOGICAL STUDY OF NUTRIENT SOLUTIONS FOR PLANT CULTURES. *In* Physiol. Researches, v. 1, no. 4, p. 133–245, 15 fig. Literature cited, p. 242–245.

COMPOSITION AND DIGESTIBILITY OF SUDAN-GRASS HAY

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INTRODUCTION

The introduction of Sudan grass (*Andropogon sorghum* var.) into the United States took place less than nine years ago (1909), but since then this crop has become widely known, and its popularity is rapidly increasing. Sudan grass, being an annual, does not make a good pasture plant, but gives excellent results as a hay or soiling crop; it might also be successfully made into silage if mixed with a legume.

RÉSUMÉ OF PREVIOUS WORK

A considerable amount of work has been done on the production of Sudan grass; and, though the yields of hay obtained varied considerably, they were as a rule satisfactory (Table I).

Table I.—*Average yields of Sudan-grass hay* (*5*)[a]

State Experiment Station.	Dry hay per acre.	State Experiment Station.	Dry hay per acre.
	Tons.		*Tons.*
Virginia	3.4	Texas	3.9
Tennessee	2.6	Oklahoma	2.9
Mississippi	5.5	Ohio (*8*)	4.3
Louisiana	3.3	Kansas (*7*)	3.1
Georgia	3.6		
Arkansas	1.1	Average	3.4

The average yields of Sudan-grass hay, as stated in Table I, have not all been calculated by the same method, but the results show that as a rule a yield of 3 to 4 tons of field cured hay per acre can be expected.

The material available to show the composition of Sudan-grass hay is limited, but a compilation of the published analyses is included here. There is a wide variation in the moisture contents of hays, due to a

[a] Reference is made by number (italic) to "Literature cited," p. 185.

Journal of Agricultural Research,
Washington, D. C.

Vol. XIV, No. 4
July 22, 1918
Key No. Iowa-6

considerable extent to the lack of uniformity in the conditions under which curing takes place; so in Table II the various constituents are expressed as percentages of the total dry matter present in the samples of hay analyzed.

TABLE II.—*Composition of the dry matter of Sudan-grass hay*

Constituent.	Maryland (6).	Virginia (4).	Texas (9).	Oklahoma (3).	Average.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Total dry matter	90.12	96.49	....	92.80	93.14
Protein	6.57	4.83	12.42	8.56	8.10
Nitrogen-free extract	51.99	51.09	45.56	48.98	49.41
Crude fiber	34.83	36.92	29.93	34.01	33.92
Ether extract	1.88	1.32	1.92	2.42	1.89
Ash	4.74	5.85	10.16	6.03	6.70

The analyses of Sudan-grass hay that have been reported are fairly uniform in all their constituents except protein and ash, which show rather wide variations, due perhaps to the conditions under which the crops were grown and the stage of growth at the time of cutting.

It is generally understood that the majority of crops alter materially in composition as ripening progresses. This change is due not only to the increase in the amount of dry matter and the decrease in the amount of water but also to a variation in the relative proportions of the individual constituents of the dry matter. These changes usually go on until the crop is practically ripe, but that this is not so in the later stages of ripening in the case of Sudan grass has been shown by Piper (Table III).

TABLE III.—*Composition of dry matter of Sudan-grass hay (4) made at various stages of ripeness*

Stage of cutting.	Before heading.	Heads appearing.	Beginning to bloom.	In full bloom.	Seeds fully mature.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Protein	8.08	6.28	5.34	4.83	4.38
Nitrogen-free extract	51.23	53.41	53.76	51.09	55.85
Crude fiber	32.00	33.11	34.42	36.92	36.02
Ether extract	1.79	1.44	1.27	1.32	1.55
Ash	6.89	5.75	5.20	5.85	5.85

As would be expected, there is a decrease in the protein and a slight increase in the crude-fiber content. These changes are marked in the case of the protein, but the other constituents are fairly constant. The significance of this is that from the time Sudan grass heads out until it is fully ripe there is very little change in the fiber content of the dry matter, and consequently the time of cutting can be delayed without much risk of the hay becoming too coarse. This suggests a distinct

advantage if the haying season is wet; the cutting of the Sudan grass may advantageously be postponed for a week or 10 days if there is a prospect of improvement in the weather.

In spite of the fact that Sudan grass is now grown in quite an extensive territory, it has been fed but little experimentally. Large amounts of Sudan hay are consumed annually, yet only in one or two cases have accurate records been kept of the results it produced.

So far only one digestion trial has been conducted with Sudan-grass hay. This work consisted of a 5-day test period with a 2-year-old bull, and the results of it are given in Table IV.

TABLE IV.—*Digestibility of Sudan-grass hay* (*6*)

Constituent.	Digestion coefficient.
	Per cent.
Dry matter	60.6
Crude protein	35.4
Nitrogen-free extract	63.3
Crude fiber	67.1
Ether extract	41.2

The digestion coefficients for Sudan-grass hay obtained at the Maryland Experiment Station compare well with those for other nonleguminous roughages (*6*).

At the Kansas Experiment Station Sudan-grass hay was compared with alfalfa hay as a roughage for dairy cows. Two lots of three cows each were used. There were two 30-day test periods. In the first period Lot I received alfalfa hay and Lot II Sudan-grass hay, while in the second test period the roughages for the two lots were reversed (Table V).

TABLE V.—*Sudan-grass hay v. alfalfa hay for milk production*

	Roughage.		Gain due to alfalfa.
	Sudan grass.	Alfalfa.	
	Pounds.	*Pounds.*	*Pounds.*
Milk produced	4,022	4,112	90
Fat produced	168	178	10
Average body weight	1,053	1,077	24

This shows a difference in production of 0.5 pound of milk per head per day in favor of the alfalfa hay. This is not a large difference, but if the experiment had been run for another 30-day period so as to facilitate the elimination of the decrease in production due to advance in lactation, there is little doubt that the Sudan-grass hay would have shown up even less favorably. The fact that the cows increased in weight when receiving the alfalfa is significant (*6*).

The Kansas records (7) also show that when the herd of milking cows was turned from a native pasture on to a Sudan pasture the average daily production of milk was increased 3.2 pounds per head, even though Sudan grass is not a first-class pasture plant. In addition, they also found that for wintering work horses and mules and young beef cattle Sudan-grass hay was of considerably less value than alfalfa hay.

EXPERIMENTAL WORK

The Sudan grass used in the work reported in this paper was grown on the College dairy farm. During the two years in which this crop has been grown there it has given good results as a soiling crop, the average yield being 11 tons of green feed per acre for one cutting. In 1916 a small amount of second growth was made into hay. Sudan grass seems to be palatable and much relished by the stock, and good results have been obtained in the feeding of both the soiling and the hay.

In 1915 analyses were made of the crop at various stages of growth. The samples were all taken from one small plot in the center of the area grown for soiling and the results of the analyses are expressed as percentages of the total dry matter present.

TABLE VI.—*Composition of dry matter of Sudan grass at various stages of growth*

Stage of growth.	Before heading.	Headed out.	Full bloom.	Half ripe.	Ripe.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Total dry matter	20.80	20.96	25.74	30.08	31.92
Protein	8.80	9.78	6.57	5.02	4.29
Nitrogen-free extract	48.12	46.04	50.19	53.32	53.73
Crude fiber	32.98	35.50	32.36	32.98	33.83
Ether extract	2.31	2.62	3.53	2.10	1.66
Ash	7.79	6.06	7.35	6.58	6.49

As the moisture decreases and the dry matter content increases in the later stages of growth of Sudan grass, a few minor changes take place in the relative proportions of the individual constituents of the dry matter. In the earlier stages of ripening the protein seems to increase, while it decreases in the later stages. The changes in the fat content are very similar to those of the protein content, but lag behind them. The changes in the proportions of nitrogen-free extract and ash are in the opposite direction to those of the protein and ether extract. Peculiarly, the relative proportion of the crude fiber to the other constituents of the dry matter appears to be greater when the plants have headed out than when the crop is ripe. The difference is not great, however, and can probably be explained by the fact that the seed, of which the yield is quite heavy, is very low in crude fiber. It has been found at the Maryland Station (6) that cleaned Sudan-grass seed contains only 1.19

per cent of crude fiber. To consider the changes broadly, it is evident that from the time the crop heads out until it is ripe no very marked alterations take place in the relative proportions of the various constituents of the dry matter present, and consequently Sudan grass does not materially deteriorate in feeding value on ripening.

The hay used in the digestion trial was from a plot yielding 2.94 tons of field-cured hay per acre at one cutting. It was cut on August 5, 1916, when in full bloom and was harvested in good condition. It was kept in the mow till used for the digestion trial in December, 1916.

The animals used were two three-quarter blood Guernsey heifers about a year and a half old and averaging 600 pounds in live weight. These animals were of 75 per cent the same breeding, being sired by Rouge of Ames (24405), a son of Rouge II's Son, while their dams were sired by Rouge II's Son (18587). From birth until the start of the digestion trial these heifers received the same care and feed. Both were pregnant and in fair condition at the beginning of the experiment, and though No. 298 was rather larger than No. 301, they were a very uniform pair in all other ways.

TABLE VII.—*Description of animals used in trial*

Animal.	Age.	Days bred.	Weight.
	Yr. mos. dys.		*Pounds.*
Heifer 298	1 6 17	63	650
Heifer 301	1 5 27	152	550
Average	1 6 7	108	600

The digestion trial was run for a period of five days preceded by a preliminary period of seven days during which Sudan grass was fed as the only source of nutriment to the heifers. In the preliminary period it was found that 20 pounds per head per day of the hay would be a convenient amount to feed; so this allowance was used throughout the experiment and the material left was weighed back daily.

It has been found that the animals had no special need of being watered twice daily, so the watering was done at the beginning of each 24-hour period and the animals were weighed before and after watering. The attendant collected the feces with a scoop and deposited them in tarred galvanized-iron vessels which were provided with covers.

A composite sample of the hay fed, and one of the orts were made at the end of the trial period. The feces from each heifer were mixed thoroughly and sampled at the end of each 24-hour period, and these samples were air-dried. At the end of the trial an aliquot composite sample was made for the feces produced by each of the heifers during the 5-day trial period.

The composite samples of feces, together with those of hay and orts, were chemically examined according to the official methods.

In Table VIII is given a summary of the hay and water consumed and the feces produced daily by each of the heifers. Only the net consumption of hay is given, and the feces production recorded opposite a daily consumption of hay is the weight of feces produced in the 24-hour period following the day during which the recorded amount of hay was consumed.

TABLE VIII.—*Summary of weight of feed and feces*

Day.	Hay consumed.		Water consumed.		Feces produced.	
	Heifer 298.	Heifer 301.	Heifer 298.	Heifer 301.	Heifer 298.	Heifer 301.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	14.2	13.4	24	27	19.1	14.9
2	17.0	16.7	39	29	21.8	20.9
3	13.0	11.6	31	17	24.6	18.4
4	7.9	10.5	28	27	21.4	21.8
5	12.4	14.1	24	26	23.9	19.8
Total	64.5	66.3	146	126	110.8	95.8

The heifers had very similar capacities for hay consumption, the difference in their average daily consumption being only about one-third of a pound (Table IX). Their capacities for water consumption were also very much alike; the heifer which consumed the smaller amount of hay drank on the average 4 pounds more water per day than did the other heifer. The production of feces followed the water consumption very closely, and the heifer which consumed the smaller amount of hay and the greater quantity of water produced the greater weight of feces.

TABLE IX.—*Composition of hay*

Constituent.	Hay offered.	Hay refused.	Hay consumed.
	Per cent.	*Per cent.*	*Per cent.*
Moisture	13.19	11.64	14.01
Dry matter	86.81	88.36	85.99
Protein	5.97	4.10	6.96
Nitrogen-free extract	43.63	42.85	44.04
Crude fiber	28.65	34.50	25.55
Ether extract	1.62	1.08	1.91
Ash	6.94	5.83	7.52

As was to be expected, the hay refused was a little more fibrous than the whole sample. The difference is so small, however, that the digestion coefficients found for the hay consumed will apply equally well to the whole sample.

TABLE X.—*Composition of feces*

Constituent.	Heifer 298.	Heifer 301.
	Per cent.	*Per cent.*
Moisture	82.39	79.13
Dry matter	17.61	20.87
Protein	2.13	2.54
Nitrogen-free extract	8.32	9.74
Crude fiber	4.35	5.24
Ether extract	.47	.54
Ash	2.34	2.81

The analyses given for the feces represent their composition when moist (Table X). Heifer 301, which consumed less hay and more water than did heifer 298, produced the feces with the higher moisture content. The bulk of the feces evidently depends to a large extent on the amount of water consumed.

TABLE XI.—*Summary of weights of nutrients consumed and defecated*

Constituent.	Heifer 298.		Heifer 301.	
	Total nutrients consumed.	Total nutrients defecated.	Total nutrients consumed.	Total nutrients defecated.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
Dry matter	55.44	19.51	57.03	19.99
Protein	4.51	2.36	4.59	2.43
Nitrogen-free extract	28.42	9.22	29.19	9.33
Crude fiber	16.40	4.82	17.02	5.02
Ether extract	1.24	.52	1.26	.52

Table XI again demonstrates the similarity between the powers of the two heifers for using roughage and also indicates that their powers of digestion are very nearly equal.

TABLE XII.—*Coefficients of digestibility*

Constituent.	Heifer 298.	Heifer 301.	Average.
	Per cent.	*Per cent.*	*Per cent.*
Dry matter	64.8	65.0	64.9
Protein	47.7	47.1	47.4
Nitrogen-free extract	67.6	68.0	67.8
Crude fiber	70.6	70.5	70.6
Ether extract	58.1	58.7	58.4

This shows that the nutrients in Sudan-grass hay are all fairly easily digested. The digestion coefficients range from 47.4 per cent in the case of the protein to 70.6 per cent for the crude fiber, while that for the total dry matter is 64.9 per cent.

A comparison of the work done at this station with that done at the Maryland station shows that the coefficients of digestibility obtained agree fairly closely for most of the nutrients present in Sudan-grass hay (Table XIII).

TABLE XIII.—*Comparison of digestion trials with Sudan-grass hay*

Constituent.	Digestion coefficients (6).		
	Maryland.	Iowa.	Average.
	Per cent.	*Per cent.*	*Per cent.*
Dry matter	60.6	64.9	63.5
Protein	35.4	47.4	43.4
Nitrogen-free extract	63.3	67.8	66.3
Crude fiber	67.1	70.6	69.4
Ether extract	41.2	58.4	52.7

The Iowa results are in all cases higher than those obtained at the Maryland station, but only in the case of the crude protein and ether extract is there a very marked difference. This may, perhaps, be due to differences in the conditions under which the hays were grown, though they are very similar in composition, or more probably to variations in the digestive powers of the animals used. Whatever the factors or factor are that bring about this difference they apparently are selective in their action.

The total and digestible nutrients in 100 pounds of Sudan-grass hay are given in Table XIV.

TABLE XIV.—*Nutrients in 100 pounds of Sudan-grass hay*

Constituent.	Nutrients.	
	Total.	Digestible.
	Pounds.	*Pounds.*
Dry matter	91.6	58.2
Protein	7.7	3.3
Nitrogen-free extract	48.3	32.0
Crude fiber	30.9	21.4
Ether extract	1.8	.9

A comparison of Sudan-grass hay with timothy and millet hay shows that these feeds are very similar in composition. The digestible nutrients in 100 pounds of dry matter of the various feeds (Table XV) have been calculated from Henry and Morrison's tables (*2*), while the digestible true protein and net energy value of 100 pounds of dry matter have been obtained from Armsby's work (*1*).

TABLE XV.—*Digestible nutrients in 100 pounds of dry matter of timothy, millet, and Sudan-grass hay*

Constituent.	Timothy hay.	Millet hay.	Sudan-grass hay.
	Pounds.	*Pounds.*	*Pounds.*
Protein	3.4	5.8	3.6
Carbohydrates	48.4	53.6	58.3
Fat	1.4	2.1	1.0
Total	54.0	64.2	64.2

The data in Table XV show that Sudan-grass hay provides considerably more nutrients than timothy hay, and, though it contains rather less digestible protein than millet hay, it appears to furnish about the same amount of total nutrients. These comparisons are made on the dry matter basis so as to eliminate variations due to changes in the moisture contents of the feeds.

The net energy value of the Sudan-grass hay has been calculated according to Armsby's method (*1*), while the digestible true protein is taken as 75 per cent of the digestible crude protein (Table XVI). These figures show that Sudan-grass hay, though deficient in protein, provides more net energy per 100 pounds of dry matter than hay from timothy or millet.

TABLE XVI.—*Digestible true protein and net energy values per 100 pounds of dry matter in timothy, millet, and Sudan-grass hay*

Item.	Timothy hay.	Millet hay.	Sudan grass hay.
Digestible true protein . . . pounds	2.5	4.6	2.7
Net energy value . . . therms	48.67	54.80	64.42

SUMMARY

(1) The dry matter of Sudan grass changes slightly in composition from the time of heading until the crop is ripe.

(2) The content of fat and protein increases in the early stages of ripening and decreases later while the changes in the nitrogen-free extract and ash content are in the opposite direction.

(3) Either as a green feed or as hay, Sudan grass is very palatable.

(4) Sudan-grass hay has a comparatively high apparent digestibility.

(5) Sudan-grass hay supplies energy to cattle much more efficiently than it does protein.

LITERATURE CITED

(1) ARMSBY, H. P., and FRIES, J. A.
1916. NET ENERGY VALUES FOR RUMINANTS. Penn. Agr. Exp. Sta. Bul. 142, 20 p.

(2) HENRY, W. A., and MORRISON, F. B.
1917. FEEDS AND FEEDING ABRIDGED. ... 440 p., 114 fig. Madison, Wis.

(3) KARPER, R. E.
1915. SUDAN GRASS. Okla. Agr. Exp. Sta. Bul. 103, 14 p., 3 fig.

(4) PIPER, C .V.
1913. SUDAN GRASS, A NEW DROUGHT-RESISTANT HAY PLANT. U. S. Dept. Agr. Bur. Plant Indus. Circ. 125, 20 p., 6 fig.

(5) ——— McCLURE, H. B., and CARRIER, Lyman.
1915. GROWING HAY IN THE SOUTH FOR MARKET. U. S. Dept. Agr. Farmers' Bul. 677, 22 p., 10 fig.

(6) SCHMITZ, Nickolas.
1916. SUDAN GRASS. Md. Agr. Exp. Sta. Bul. 194, p. 47–62, 7 fig.

(7) THOMPSON, G. E.
1916. SUDAN GRASS IN KANSAS. Kans. Agr. Exp. Sta. Bul. 212, 29 p., 8 fig.

(8) WILLIAMS, C. G.
1916. SUDAN GRASS. *In* Ohio Agr. Exp. Sta. Mo. Bul., v. 1, no. 3, p. 67–70, 1 fig.

(9) YOUNGBLOOD, B., and CONNOR, A. B.
1915. SUDAN GRASS. Texas Agr. Exp. Sta. Bul. 172, 28 p., 7 fig., 1 col. pl.

WATER-HOLDING CAPACITIES OF BEDDING MATERIALS FOR LIVE STOCK, AMOUNTS REQUIRED TO BED ANIMALS, AND AMOUNTS OF MANURE SAVED BY THEIR USE

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For 25 years investigators and teachers have been expressing erroneous conclusions as to the relative values of shavings, sawdust, and the straws for bedding live stock. These conclusions are based upon a table showing the relative liquid-absorbing capacities of various substances which appeared in 1893 (*5*).[1] This table, which follows, was adapted from Deherain (*4*).

Absorption of liquids by litter

Kind of litter.	Water retained by 100 kgm. of material after 24 hours.	Quantity of material necessary to replace 100 kgm. of wheat straw.
	Kgm.	*Kgm.*
Wheat straw	220	100
Barley straw	285	77
Oat straw	228	96
Partially decomposed oak leaves	162	136
Peat	500–700	40
Sawdust of poplar wood	435	50
Spent tan bark	400–500	48
Air-dried vegetable mold	50	440

According to this table sawdust has almost twice the water-holding capacity of wheat or oat straw. Not only has this point been repeatedly referred to, but the conclusions have also been drawn that sawdust or shavings will go nearly twice as far as straw as bedding for live stock and will save a much larger portion of the liquid manure.

The above table, or portions of it, have been copied in a number of publications (*2, 3, 7*).

On the basis of these figures, the statement is made in Vermont Bulletin 206 that—

> Nine pounds of straw or six pounds of shavings are needed to absorb a cow's 24 hour voidings.

Special Circular 11 of the Dominion of Canada Experimental Farms (*1*) states concerning "dry sawdust and fine shavings" that—

> Their absorptive capacity according to fineness and dryness is from two to four times that of ordinary straw.

[1] Reference is made by number (italic) to "Literature cited," p. 190.

The values given in this old French table are reversed by tests on the absorptive capacity of oat straw, wheat straw, and shavings, conducted by the writer in the spring of 1917. These tests show that oat straw absorbs 15 to 20 per cent more water than wheat straw and more than twice as much as ordinary commercial mixed shavings. The tests are well substantiated by records kept of the amount of bedding material of the different kinds actually used for different classes of animals.

In order to determine the water-holding capacity of the various materials, weighed quantities (5 to 7 pounds per sack) were sacked loosely and soaked for 12 hours. The sacks were then hung in a room in a barn, and after 5 hours, when dripping had practically ceased, were weighed. They were weighed again after hanging for 24 hours. This test was repeated several times. There was a small variation from time to time, probably due to differences in the particular samples of material obtained and to differences in the rate of evaporation on different days. However, they were relatively the same in each test. In addition to oat straw, wheat straw, and two kinds of shavings which were being used for bedding purposes, some cut oat straw, some mixed sawdust, and some very light, fine white-pine shavings were obtained for these tests. Approximate averages of the results of the tests are given in Table I.

TABLE I.—*Water-holding capacity of litter*

Material.	Water retained by 100 pounds of material after 24 hours.	Relative water-holding power after 24 hours.
	Pounds.	
Oat straw (whole)	250	100.0
Cut oat straw (about ½-inch lengths)	244	97.6
Wheat straw	210	84.0
Mixed shavings from Chicago car load	119	47.6
Mixed shavings from local planing mill	130	52.0
Mixed sawdust from local planing mill	160	64.0
Fine, dry white-pine shavings	185	74.0

It will be noted that whole oat straw retained slightly more water than cut oat straw, about 19 per cent more than wheat straw, and twice as much as the ordinary mixed shavings used for bedding material. Whole oat straw came out slightly above the cut oat straw in every test made.

The fine white-pine shavings and the sawdust retained considerably more water than the coarser mixed shavings, the white-pine shavings retaining three-fourths as much water as oat straw, and the sawdust two-thirds as much. It was impossible to get any accurate comparison between shavings and sawdust of the same kind, because the only kind of sawdust obtainable was mixed. The water-holding capacity of the sawdust varied more than that of any of the other materials.

At the same time that these tests were being made, records were being kept on the relative amounts of oat straw, wheat straw, and shavings required to keep beef cows, dairy cows, and horses bedded, and on the amounts of manure saved by the use of each kind of bedding.

Twelve head of beef cows kept in single stalls were divided into three comparable lots. One lot was bedded with oat straw, one with wheat straw, and one with shavings from a car load bought in Chicago. The wheat-straw and shavings lots were reversed at the middle of the 60-day period. With the dairy cows only two lots were used, 9 head in one lot and 10 head in the other. One lot was bedded with oat straw and the other with shavings from the local planing mill. The lots were reversed at the middle of the 30-day period. Only 3 horses were used: draft mares in box stalls, one bedded with each kind of material. The shavings used were from Chicago.

The animals were all handled in the usual way. The beef cows were out of the barn about 9 hours a day, the dairy cows about 8½ hours, and the horses about 9. No special attempt was made to regulate the amount of bedding used, the men in charge of each barn bedding as usual. The barns were cleaned out daily—that is, the manure and soiled part of the litter were removed. Table II shows the amount of bedding used.

TABLE II.—*Material used in keeping animals bedded*

Animals, period, and material.	Total bedding used.	Amount per animal per day.	Relative amount used.
Horses (1 per lot, 49 days):	*Pounds.*	*Pounds.*	
Oat straw	716	14.61	100
Wheat straw	844	17.22	118
Shavings	1,192	24.32	166
Beef cows (4 per lot, 60 days):			
Oat straw	1,766	7.36	100
Wheat straw	1,928	8.03	109
Shavings	3,207	13.36	182
Dairy cows (9½ per lot, 30 days):			
Oat straw	2,064	7.24	100
Shavings	2,892	10.15	140

In keeping the animals bedded, 40 to 82 per cent more shavings than oat straw and 9 to 18 per cent more wheat straw than oat straw were used. About 15 pounds of oat straw per day was required to keep one of the horses bedded, about 7⅓ pounds to keep one of the cows bedded. The horses were on an earth floor, the cattle on concrete floors. The Ohio Station found that about 7 pounds of straw were needed for steers on concrete floors (*6*).

From the fact that the oat straw was capable of absorbing more liquid than wheat straw or shavings, one might suppose that more of the manure from the animals could be saved by the use of oat straw. In this experiment, however, about the same amount of animal excreta was saved, regardless of the kind of bedding used. To be sure, less oat

straw was used as bedding to save the same amount of excreta. Table III shows the material removed.

TABLE III.—*Amount of manure saved by use of the various litters*

Animals and material.	Total manure removed.	Bedding used.	Excreta removed.	Excreta removed per animal per day.
Horses:	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Oat straw	3,551	716	2,835	57.8
Wheat straw	3,409	844	2,565	52.3
Shavings	3,925	1,192	2,733	55.7
Beef cows:				
Oat straw	10,227	1,766	8,461	35.2
Wheat straw	10,820	1,928	8,892	37.0
Shavings	12,190	3,207	8,983	37.4
Dairy cows:				
Oat straw	17,831	2,064	15,767	55.3
Shavings	18,214	2,892	15,322	53.7

While there is a variation of several per cent in the amount of excreta saved with each class of animals with the different kinds of bedding, still the variations are not large and are not consistently in favor of any one kind of material. It is evident that there is no very important difference in the amount of excreta saved as a result of the use of one or another of these materials.

SUMMARY

(1) The common belief that the shavings commonly used for bedding live stock have much greater water-holding capacity than straw is erroneous. Oat straw retained approximately twice as much water as shavings and 15 to 20 per cent more than wheat straw.

(2) To keep animals bedded, 40 to 82 per cent more shavings than oat straw and 9 to 18 per cent more wheat straw than oat straw were required.

(3) The amount of animal excreta removed from the barn in the manure was about the same regardless of the kind of bedding material used.

LITERATURE CITED

(1) [1917] BARNYARD MANURE. [Canada] Exp. Farms Spec. Circ. 11, 4 p.

(2) BEAL, W. H.
1904. BARNYARD MANURE. U. S. Dept. Agr. Farmers' Bul. 192, 32 p., 4 fig.

(3) BURDICK, R. T.
1917. CONCERNING FARM MANURES. *In* Vt. Agr. Exp. Sta. Bul. 206, p. 53–72.

(4) DEHERAIN, P. P.
1902. TRAITÉ DE CHIMIE AGRICOLE. ed. 2, 969 p., 88 fig. Paris.

(5) HÉBERT, A.
1893. FARM MANURE. *In* Exp. Sta. Rec., v. 5, no. 2, p. 141–158.

(6) THORNE, C. E.
1907. THE MAINTENANCE OF FERTILITY. Ohio Agr. Exp. Sta. Bul. 183, p. 195–228, illus.

(7) WINTER, O. B.
1915. LOSSES AND PRESERVATION OF BARNYARD MANURE. Mich. Agr. Exp. Sta. Circ. 26, 8 p.